DETERMINING A POSITION OF OBJECTS

FIELD OF THE INVENTION

The present invention relates to the deter-
mining of the position of objects. In particular, the
5 present invention relates to a new and improved method
of determining the location and position of objects in
relation to each other by means of electromagnetic
signals.

10 BAKCKGROUND OF THE INVENTION

The location method based on electromagnetic
signals has been described, in a very general way in-
dependent of the subject of application, e.g. in pat-
ent publications US5747996, US4346384 and DE3326476.
15 In one embodiment, the device comprises a set of sig-
nal sources, a set of receivers and one or more signal
generators which are used to generate a set of trans-
mitter signals known as concerns their tense to be
transmitted by signal sources. In addition, the afore-
20 mentioned patent publications disclose an analysis
method for processing the output signals of the re-
ceivers and for using them in calculating the position
of an object in relation to another object. Common to
the devices described in the publications is that the
25 signal transmitters have been attached to the object
in a manner geometrically rather restricted.

In addition, in publications US5747996 and
US4346384 one requires that the signal sources are or-
thogonal between themselves. Thanks to the orthogonal-
30 ity, there is no correlation between the signals
transmitted by the signal sources, i.e. the signals do
not have an effect on each other that would disturb
the determining of location. In addition, in publica-
tion US5747996 one requires that the receivers are
35 coils placed on the same level. The geometric require-

ments are used to facilitate and speed up the signal analysis and to eliminate the possible sources of error having effect on the positioning result.

5   In the co-ordinate system of an object, the location method based on known signal sources is used e.g. in magnetoencephalography (MEG), in which one measures the weak magnetic fields generated by the neural activity of a human being or other organism that are dependant on time and place. Based on the

10 measured magnetic field values, one tries to locate the source areas that generated the observed field. In magnetoencephalography, the head of a testee is⁻ as close as possible to the set of detectors i.e. receivers consisting of extremely sensitive supraconducting

15 detectors, the geometry of which is known. The position of the head in relation to the measuring device is determined using, as known signal sources, coils attached to the surface of the head the magnetic field generated by whom may be approximated by the field of

20 a magnetic dipole.

     As receivers, the measuring detectors of the measuring device are used that are also used for the receiving and measuring of the actual brain signals to be measured. The basic principles of the method have

25 been described e.g. in publications *SQUID'85: Superconducting Quantum Interference Devices and their Applications*, 1985, pages 939-944 and *Proceedings of the 7th International Conference on Biomagnetism*, 1989, pages 693-696.

30   The actual MEG measurements are usually implemented as repetition measurements, in which a response generated by the brain, followed e.g. after a certain stimulus is measured several times successively, and a mean value of the measurement results

35 time-locked in relation to the stimulus is calculated. When using the mean value of the measurement results

the effect of noise may be attenuated by a factor
which is vice versa proportional to the square root of
the number of repetitions. One problem with the repe-
tition measurements is their long duration, because of
5   which the head of a testee may move during the meas-
urement. From this automatically follows that the po-
sition of the source of the response generated by the
brain changes in relation to the measuring device in
the middle of measurement, thereby causing errors to
10   the final analysis.

Traditionally, the position of the head has
been determined solely in the beginning of the meas-
urement so that each head positioning coil has been
activated and the magnetic field generated has been
15   measured one by one, in which case the location method
has been rather slow. After the location, the testee
has been asked not to move his head until the end of
the repetition measurement.

The errors resulting from the movement of
20   head during the measurement may be avoided by a con-
tinuous measurement of position. In that case, one has
to be able to use the measuring device simultaneously
also for the measuring of other transmitter signals
than the ones to be generated in the positioning. One
25   way to eliminate the effect of the transmitter signals
on the useful signal to be measured, i.e. on the re-
sponse signal generated by the brain is to set the
frequencies of the transmitter signals far away from
the frequency band to be examined and to filter meas-
30   urement data appropriately in the frequency plane.
This kind of solution is presented in publication *Bio-
mag2000, 12th International Conference on Biomag-
netism, Book of Abstracts*, p. 188, Peters, H. et al.
Another solution is the filtering of the transmitter
35   signals from the output signals of the receivers by
subtracting the shares corresponding to the transmit-

ter signals from the measured signals, in which case one has to know the strengths and wave shapes of the transmitter signals to be measured.

When trying to determine the position of an
5 object constantly or repeatedly at short intervals the signal transmitters have to be activated simultaneously and one has to be able to tell the difference between the simultaneous components generated by different transmitters and the measurement signals. The
10 method should distinguish the frequency components as efficiently and accurately as possible using a data collection time as short as possible. In a generally used distinction method the frequencies and the data collection time are adjusted so that the signal compo-
15 nents are orthogonal between themselves at the time interval being examined. If the phase of the transmitter signal is known, then the amplitude of each signal component is achieved directly by calculating the projection of the signal vector consisting of the meas-
20 urement results for the basis vector corresponding to the signal component being examined that consists of the computational values of the basis function known as concerns its frequency. Applications based on the orthogonality of the basis vectors have been described
25 e.g. in publications "The use of an MEG device as a 3D digitizer and a motion correction system", de Munck et al Proceedings of the 12th International Conference on Biomagnetism, Helsinki, Finland. In this description, the effect of the non-orthogonality has been taken
30 into account on a principal level. In the positioning method described, the orthogonalisation of the transmitter signals, however, substantially reduces the amount of computation associated with the positioning, so in an implementation in practice, the transmitter
35 signals are orthogonalised.

The requirement of orthogonality sets re-
quirements to the frequencies to be used as well as to
the data collection time, and in addition, the suppo-
sition of orthogonality for non-orthogonal signals
5   causes great errors in the computed amplitude coeffi-
cients and thereby also in the positioning. In the
signal analysis described above one tries to use sig-
nals collected from a time interval as short as possi-
ble in order that the positioning would be as real-
10   time as possible and the movement of the objects would
be as slight as possible during the data collection of
the positioning measurement. Dependable positioning
measurements have been made in magnetoencephalography
using a data collection time of solely 100 ms.

15   Even at a time interval like this objects may
move, which makes the positioning result worse. Due to
the possibly large movement of the objects, the
strengths of the signals measured by the receivers may
vary from the lowest limit of a signal being observed
20   rapidly up to the upper limit of the dynamic area of
the receivers. The variation may be significant espe-
cially in small distances, since the strength of a
measured signal is vice versa proportional to the
third power of the distance of objects. In addition to
25   this, the same transmitters may be used in different
measurements for objects of very different sizes and
located in different distances in relation to the
transmitters. The repeated succeeding of the measure-
ments to be made in different situations requires that
30   the strengths of the transmitter signals measured by
the receivers constantly remain within certain limits.
The problem has been solved by using an adjustment al-
gorithm which controls the power of the transmitters
in such a way that the amplitudes of the signals meas-
35   ured by all the receivers remain above a certain low-
est limit and below a certain upper limit. The return

switching of the transmitter signals has been described e.g. in patent publication US5747996.

OBJECTIVE OF THE INVENTION

5   The objective of the present invention is to eliminate the drawbacks referred to above or at least significantly to alleviate them. One specific objective of the invention is to disclose a new type of method for implementing the positioning measurement as

10   quickly and accurately as possible. One further objective of the present invention is to disclose a measuring method which is numerically simple and efficient and in which the non-orthogonality of the signal sources does not do any harm to the accuracy of the

15   final result. Yet another objective of the present invention is to disclose a computation method which enables one to calculate the position of an object almost in-real time and thus eliminate the errors caused by the movement of the object in the actual measure-

20   ment, e.g. in magnetoencephalography. It is still another objective of the present invention to a disclose a new kind of correction method of computation by which the measured distributions of amplitudes may be corrected in order to remove the errors resulting from

25   the non-orthogonality and possible other disturbances from the amplitude or distribution of amplitudes determined to the signal, depending on the number of receivers.

30 ## DESCRIPTION OF THE INVENTION

       The invention relates to a method which enables one to determine the position and location of an object in relation to another object by means of electromagnetic signals. In the arrangement in accordance

35   with the invention there are two objects, of which to the one there are attached signal sources, i.e. trans-

mitters which generate electromagnetic signals, and
the other object contains one or more transmitters for
measuring the transmitter signals. Usually the object
containing transmitters is the one whose location or
5   position is of interest and which is the object of the
measurement. For example, in biomagnetic measurements
the object associated with the transmitters is the
head of a human being or another restricted part of
the body on whose surface the transmitters are placed.
10   By means of the arrangement in accordance with the in-
vention it is possible to find out the location and
position of the head, in which case the source areas
of the signals generated by the brain may be shown in
the co-ordinates of the head. The same receivers are
15   used to measure the signals generated both by the
brain and the transmitters.

The signal transmitters located in known lo-
cations in the co-ordinate system of the transmitter
object, may be activated so as to generate signals of
20   different frequencies either simultaneously or by
turns so that the frequencies and wave shapes are op-
tional. Due to this, the arrangements associated with
the transmitters, e.g. as regards the geometry and the
signals used, become considerably more simple than be-
25   fore. The amplitudes of the signals generated by dif-
ferent transmitters are measured using the receivers
of another device the mutual geometry of which is ei-
ther known beforehand, or is determined during the po-
sitioning. As concerns the actual measurements, it is
30   sufficient that one is able to find out the mutual ge-
ometry of the transmitters and receivers, since the
placement of the transmitter in the object is usually
known. Thus, when the geometry of the receivers and
transmitters as well as the amplitude distribution of
35   the signals sent from the transmitters is known, the
actual object signals measured from the object by re-

ceivers and their original location may be determined
in relation to the transmitters and thus in relation
to the object.

The invention is based on the use of signals
5   generated by electromagnetic or acoustic transmitters
attached to an object and measured by receivers of an-
other object in an analysis as a result of which the
relative location or position of the objects or both
can be calculated. The positioning may be constant us-
10   ing a rapid computation method of amplitudes, and in
successive measurements, vectors possibly partly tem-
porally overlapping and generated by the measured sig-
nal values.

In the location method of the invention one
15   allows the non-orthogonal basis vectors of the trans-
mitter signals, in which case the frequencies, wave
shape and data collection time of the signals to be
transmitted may be selected quite freely. The non-
orthogonal projection method to be used in the calcu-
20   lation and accentuated by basis vector inputs is nu-
merically a very fast and accurate operation compared
to the other signal analysis methods used. Unlike in
the article of de Munck referred to above, in this in-
vention the amount of the additional computation
25   caused by the non-orthogonality of the transmitter
signals is in practice negligible. In the method it is
possible to use transmitter signals the phases of
which are unknown. In that case, the phases may be
solved by calculating the amplitudes for appropriately
30   selected basis vectors which can have a difference in
phase in relation to the actual basis vectors of the
transmitter.

By means of the method of the invention it is
possible to further estimate, in addition to the
35   transmitter signals, the amplitudes of known sources
of interference, in which case their interfering ef-

fect may be removed. Interferences of this kind in-
clude specially the basic frequency of the network
frequency and its harmonious components.

In order that the matching of the measured
5 and computed amplitudes would be as precise as possi-
ble one needs information on the interference and
noise appearing on the channels. Since these may vary
as a function of time, it is advantageous to measure
the parameters in question in conjunction with the po-
10 sitioning measurement. This may be implemented by sub-
tracting the estimated signals from the measured sig-
nals and by using the power of the remaining signal in
some frequency band.

According to one embodiment of the invention
15 it is possible to estimate signal components that dif-
fer from the actual signal shapes to be estimated that
are generated by transmitters or known sources of in-
terference.

The receivers may also be used during the po-
20 sitioning measurement to measure also other signal
sources than the transmitter signals. This is imple-
mented by subtracting the share of the computed trans-
mitter signal amplitudes from the output signal of
each receiver at each moment of time. Thanks to the
25 invention, the subtraction succeeds better than before
because the estimation of the amplitudes and phase of
signals is more precise than in the previously known
devices. The filtering enables a continuous position-
ing when measuring also other signals than transmitter
30 signals.

The strengths of the transmitter signal am-
plitudes to be observed in the receivers may be ad-
justed by return switching, in which one takes into
account the signals measured by the whole set of re-
35 ceivers. In this way, a sufficient signal noise ratio
is ensured in every measurement situation.

The accuracy of the positioning of the inven-
tion may be improved by measuring the interference
level of the signal by subtracting from the measured
signals the signals determined by means of known basis
5   signal forms. The differential signal thus remaining
tells about the fact of how dependable each estimate
is, and this information may be used for making the
matching more precise by taking into account the noise
level. The noise level may also be measured by esti-
10   mating the signal or signals that differ from the
shapes of the transmitter signals and from those of
the interferences known by us, e.g. a network fre-
quency interference. By estimating an amplitude for
this kind of signal by the method of the invention,
15   information is gained on the fact of how much the pre-
sumed model of the signal space differs from reality.

The advantage of the present invention over
prior art is that by means of the arrangement of the
invention, the clarifying of the amplitude distribu-
20   tions of signals sent by a certain set of transmitters
and received by a certain set of receivers, with one
or more receivers, becomes more precise and effective
than before. Likewise, thanks to the invention, the
choosing of the signals to be transmitted becomes con-
25   siderably more free than before, specially in terms of
frequency and phase. Thanks to the invention, the sig-
nals do not have to be orthogonal with each other.

Further, thanks to the invention it is possi-
ble to take into account, e.g. in the MEG measure-
30   ments, the possible movements of the head during the
measurement of the actual useful signal. In addition,
the invention allows the elimination of external
sources of error in order to improve the accuracy of
the measurement results.

35   Further, the method and device of the inven-
tion can be easily modified, and the correction calcu-

lation to be implemented in the invention may be implemented at a measuring and calculation step each time most suitable.

5   **DETAILED DESCRIPTION OF THE INVENTION**

In the following section, the invention will be described by the aid of a detailed example of its embodiment with reference to the accompanying drawing which schematically represents one measuring device
10 arrangement in accordance with the invention.

In the following section, one mode of implementation of the invention will be described. The drawing illustrates, on a principal level, the measurement arrangement of the invention that comprises a
15 transmitter part g_1, ..., g_n and receiver structure which comprises a set of receivers 1, ..., K. The drawing shows only one receiver antenna, but it is obvious to a person skilled in the art how an arrangement of several antennas is implemented in accordance with the
20 drawing. The receiver is used to measure the amplitudes of the transmitter signals c_{1k}, c_{2k}, ..., c_{Nk} and of the possible interference η_k. In the symbols of the signals, parameter k refers to the measurement result to be obtained k from one sent signal due to the fact
25 that each signal is received, seen from the starting point, with k receiver.

In addition in the drawing there is shown the return switching AGC controlling the transmitters as an input to which there are the final measured signal
30 amplitudes $\hat{u}_k$. Based on the obtained amplitudes, the return switching controls the transmission power of the transmitters so that the signal-noise ratio constantly remains on the desired level in order to achieve the best possible measurement result. Further,
35 in the drawing there is shown a filter AF, which is arranged in between the receivers 1, ..., k and the out-

put of the measuring device in order to filter the
signals transmitted by the transmitters from the ac-
tual useful signal $s_k(t)$.

In the measuring arrangement there is, ac-
5   cording to the above-mentioned, a measuring device
consisting of K receivers that is simultaneously
stimulated by a signal source g attached to the object
to be positioned by N. The receiver k is used to col-
lect signal over the time interval T , and over the
10   signal components $e_1(t)$, ..., $e_M(t)$ ($M > N$ associated
with different transmitters g when wishing to estimate
from the transmitter signals also other than their ba-
sic components 1, ..., N). For measuring the amplitudes,
a signal vector consisting of signal values collected
15   from different moments of time is first projected for
basis vectors corresponding to different frequencies
as well as for basis vectors being at the same fre-
quency with these that have a difference in phase of
about 90 degrees in relation to the previous basis
20   vectors.

In the drawing, the calculation of the pro-
jections has been described by means of certain inte-
grals of the products of the signals measured in the
manner of continuous functions and of those of the ba-
25   sis vectors over the time T. It must be noted that in
a digital implementation, instead of the integrating,
summing is used as a numerical integrating that is in
fact an estimate of a constant integrating. The digi-
tal implementation is, however, in no way restricted
30   from the application possibilities of the present in-
vention.

If desired, the integrand may be accentuated
by some window function w. The M dimensional projec-
tion vector u obtained after the projection is cor-
35   rected by matrix $\mathbf{F}_2$, which is an $(M \times M)$ dimensional
matrix depending on the basis vectors so that $\hat{u} = \mathbf{F}_2{}^*u$,

in which case $\hat{u}$ is a vector containing the amplitude coefficients of the transmitter signals and those of the identical signals being 90 degrees in a different phase with these as well as those of other wave shapes to be estimated.

The formal mathematical grounds of the correction are as follows. The signal vector consisting of the signal values measured at different moments of time is marked by $s:$, and the matrix containing the basis vectors as horizontal vectors is marked by E, in which case the measured signal is of the form $s = E^T*\hat{u}$, from which a pseudo inverse solution $\hat{u} = inv(E*E^T)*E*s = inv(E*E^T)*u$ is obtained, in which case T refers to the transpose of the matrix, and $inv()$ to the inverse matrix of the matrix. In that case, the matrix $F_2 = inv(E*E^T)$ and F_1 is a unit matrix. The correction required by the non-orthogonality may also be done solely to the basis vectors by using matrixes $F_1 = inv(E*E^T)*E$ and $F_2 =$ is a unit matrix, or together both to the basis vectors and projection vectors so that F_1 and F_2 together form the correction operation. Based on the signal amplitudes measured on different channels it is possible to calculate the relative location or position of objects, or both.

The matrixes F_1 and F_2 are the same to all the K receivers, so only the projection vector u has to be calculated separately for different receivers, and thus the amount of the additional computation resulting from the non-orthogonality of the transmitter signals is very small. Based on the signal amplitudes measured on different channels it is possible to calculate the relative location or position of the objects, or both.

Since it is possible to measure with the device the amplitudes of arbitrary signal components, the signals used in the above-mentioned description

and generated by a stationary object may be replaced with a larger set of basis vectors that are able to represent the wave shapes generated by a moving object. The movement may be modelled e.g. by amplitude

5   modulating the original signal by wave shapes differing from standard ones. This makes it possible to determine the location even of a moving object more precisely and thus take into account the change in the signal amplitudes due to the movement of the object.

10   The filter AF subtracts from the signal measured at each moment of time the amplitudes of the transmitter signals c_1, ..., c_N and the ones of the counterparts of these transferred in time, so the location measuring based on the signals of the transmitters

15   does not do any harm to the actual simultaneous measuring.

The return switching AGC is implemented by calculating the RMS values of each measured signal from time interval T over the set of transmitters

20   1...K and by adjusting based on this the transmission power of individual transmitters so that the maximum of the estimated signal components over the set of receivers remains approximately standard.

The invention is not restricted merely to the

25   examples of its embodiments referred to above, instead many variations are possible within the scope of the inventive idea defined by the claims.